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INVESTIGATIONS OF THE ROLE OF PHONOLOGICAL PROCESSING IN VISUAL WORD RECOGNITION USING THE FAST PRIMING TECHNIQUE

A Thesis Presented

by

ALEXANDER B. BILSKY

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

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Psychology

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PHONOLOGICAL PROCESSING IN VISUAL WORD RECOGNITION
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

GENERAL INTRODUCTION

Visual word recognition is the process of identifying printed or written words during reading. One basic question about visual word recognition concerns what role phonological coding plays in normal, skilled reading. One way to recognize a printed word would be to access the phonology, or the sound, of the word being read. It is also possible that readers could recognize words by some means other than phonological coding, however. Readers might determine the identity of a word by a purely visual or orthographic method, relying only on the word's constituent letters, rather than its sound.

Some researchers have theorized that phonological coding might be an important step in visual word recognition because spoken language seems to have a much more privileged status in human cognition than written language. The human brain seems to be specially adapted by evolution for speaking and for understanding speech. Spoken language in humans probably developed 100,000 years ago or earlier (Rayner & Pollatsek, 1989), and humans learn to speak and to understand speech at a very young age without needing instruction or special effort. Writing systems, on the other hand, are a human invention for which the brain does not seem especially adapted. Writing developed much more recently than spoken language, within the last few thousand years. Finally, learning to read and write requires a great deal of instruction and effort, and many never learn to read well even with education. Since spoken language seems to have a special position in human cognition, it would make sense for humans to use the phonological codes necessary for understanding spoken language in the process of recognizing the written word.

Several theorists have put forward models of visual word recognition. Most such models involve progressive activation of different levels and types of information in memory. In some of the models, backward interaction between higher and lower levels of information is also possible. In general, the first step in models of visual word recognition is the activation of visual or orthographic information. After some process which varies from model to model, the appropriate semantic information, i.e. the word's meaning, becomes activated. In this paper, the point at which a word's meaning becomes activated will be considered the point at which word recognition, or lexical access, has taken place.

Our question about the role of phonology in visual word recognition can be (and has been) expressed in terms of such models. If phonological coding is an important step in visual word recognition, then a model of reading should include a level of phonological information which is activated by the visual or orthographic information and which, in turn, activates the semantic information (see Figure 1). I will call models which do this *early phonology* models. Van Orden (1987) proposes such a model. It should be pointed out, though, that no early phonology model can rely solely on phonology to reach the appropriate semantic information because some written words have homophones, words which are pronounced the same but are spelled differently. In his model, Van Orden (1987) solves this problem by employing a spelling check after most of the work of word recognition has been done.

Alternately, visual word recognition may not normally require phonological coding. If so, a different model of word recognition is required. In such a model, phonological information would usually be activated only after semantic information were activated (see Figure 2). I will call models of this type *late phonology* models. Two important factors affect the design of late phonology models. First, we know that printed words can at least sometimes be identified on the basis of phonological codes because readers have little trouble identifying nonsense words like SUTE which sound like real words. It is for this reason that late phonology models must allow phonological information occasionally to be activated before semantic information. Second, whether or not phonological information is activated before lexical access, research has shown that phonology is likely to be activated post-lexically to enhance memory and, therefore, aid sentence comprehension (e.g. Slowiaczek & Clifton, 1980). This is why phonological information is activated after semantic information in late phonology models. Paap, Newsome, McDonald, and Schvaneveldt (1982) have proposed a model in which word recognition is achieved without the involvement of phonological processing.

Another possible scheme for a word recognition model is one in which visual information activates a phonological route and a non-phonological route to semantic information (see Figure 3). The phonological route and non-phonological route would work in parallel. This is known as a "dual-route" model. The two routes could operate independently in a horse-race scheme, as in Coltheart (1978), or in cooperation, as in Carr and Pollatsek (1985). Dual-route models vary in the extent to which they allow the phonological route to influence lexical access.

Research on the role of phonology in visual word recognition has had mixed results. Some studies have suggested that phonological codes do play a central role in visual word recognition (e.g. Lesch & Pollatsek, 1995; Perfetti & Bell, 1991; Perfetti, Bell, & Delaney, 1988; Pollatsek, Lesch, Morris, & Rayner, 1992; Rayner, Sereno, Lesch, & Pollatsek, 1995; Van Orden, 1987; Van Orden, Johnston, & Hale, 1988). Other studies have demonstrated an effect of phonological coding on lexical access only for low frequency words (e.g. Jared & Seidenberg, 1991; Seidenberg, Waters, Barnes, & Tanenhaus, 1984). Finally, some research has indicated that phonological codes are used only for post-lexical processing (Daneman & Reingold, 1993; Daneman, Reingold, & Davidson, 1995).

Since different experimental methodologies have given different answers for the same question, it is worthwhile to examine the characteristics of the different methodologies. The processes which we wish to understand are those that occur early (pre-lexically) in visual word recognition during normal, skilled reading. The best experimental methodology would use a task as much like normal, skilled reading as possible. In other words, the task would be naturalistic. Second, the best methodology would tap early word recognition processes and would be as little contaminated by other processes as possible. The likelihood of achieving this goal is affected not only by what the task requires the subject to do, but also by the length of time the relevant stimulus is visible and by the length of time which it takes the subject to respond.

One methodology which has been used to study the role of phonology in visual word recognition is naming. In naming studies, the time it takes to read a word aloud is used as a measure of the time it takes to recognize a word. Of most interest here are naming studies in which the spelling-to-sound regularity of words has been the independent variable. The reason for manipulating spelling regularity has to do with another basic question that reading researchers have tried to answer: the question of how a phonological code, or a pronunciation, is derived from a printed word. A complete model of visual word recognition must explain how the relevant phonological information is activated for each word. Of course, a system for producing phonology pre-lexically would likely be very different from a system to produce phonology post-lexically. Because of this, models of pre-lexical phonological code production are particularly relevant to the issue of the importance of phonology in visual word recognition. Variables which should affect pre-lexical phonological code production should influence visual word recognition as well, if phonological codes are important in visual word recognition.

Spelling-to-sound regularity is a variable which should influence pre-lexical, but not post-lexical, phonological code production. Written English words vary in the extent to which one can derive their pronunciations by applying regular English spelling-to-sound rules. The word CAKE, for example, is completely regular. The word PINT, on the other hand, is irregular. A pre-lexical phonological code production system might be sensitive to these spelling-to-sound regularities. A post-lexical system would not need to refer back to the spelling of a word since its meaning would have already been activated. If a pre-lexical phonological code production system were sensitive to spelling regularity, the degree of regularity of a word might affect the time required to produce its phonology pre-lexically. Therefore, if phonological codes were indeed produced pre-lexically, the time required to identify a word might be influenced by regularity. In fact, many studies have found that naming time is longer for irregular words than for regular words (e.g. Baron & Strawson, 1976; Glushko, 1979; Stanovich & Bauer, 1978). Seidenberg et al. (1984) have qualified this finding by showing that the regularity effect in naming is restricted to low-frequency words.

The regularity effect findings have a number of implications. First, they indicate that models of pre-lexical phonological code production should be sensitive to spelling-to-sound regularity. This does not mean that these models must contain explicit rules. Models with explicit rules (e.g. Coltheart, Curtis, Atkins, & Haller, 1993) and without (e.g. Seidenberg & McClelland, 1989; Van Orden, Pennington, & Stone, 1990) can account for these findings. Secondly, the result indicates that phonological codes may be involved in the process of word recognition, at least in the relatively slow process of identifying low-frequency words.

Some consideration of the naming methodology, however, makes the implications of the regularity effect findings for models of word recognition less clear. First, the studies involve reading words in isolation, rather than normal reading. Even more seriously, it is not certain that naming task results reflect the word recognition processes in which we are interested. It is possible that subjects performing the naming task may not actually access the meanings of the words presented to them. In addition, the naming task requires processes, e.g. speech production, which are not required in normal silent reading. The time required to complete these additional processes is reflected in the relatively long reaction times (averaging approximately 500 ms) obtained in the naming task. Merely recognizing a word, on the other hand, probably takes only between 100 and 200 ms on average (Rayner & Pollatsek, 1989). Since naming times may reflect processes other than those in which we are interested, results of naming time studies must be viewed with caution.

Several paradigms involving homophones or pseudohomophones (nonwords which sound like real words) have also been used for studying phonological processing in word recognition. In Van Orden's (1987; Van Orden et al., 1988) experiments, subjects had to judge whether or not each word presented was a member of some given category. The words presented included legitimate members of the categories (e.g. ROSE for the category

FLOWER), homophones and sometimes pseudohomophones of category members (e.g. ROWS), as well as words or nonwords that were only visually similar to category members (e.g. ROBS). He found that subjects were much more likely to make false positive errors to homophones or pseudohomophones of category members than to the visually similar words or nonwords. The findings indicate that subjects were coding the words phonologically even though they could have avoided errors by not coding the words phonologically. This suggests that phonological coding is an inevitable part of visual word recognition. In a study similar to Van Orden's, however, Jared and Seidenberg (1991) reported that the homophone effect was limited to low-frequency homophones when the categories used were broader in scope.

Whether or not the effect is limited to low-frequency words, the finding that phonological coding is obligatory for a great many, if not all, words is quite striking. However, the categorization methodology falls victim to some of the same criticisms as naming. Again, the task is not very similar to normal reading. Unlike naming studies, the categorization task does necessitate that the subject process the meanings of words. However, categorization judgments require a great deal more cognitive activity than mere lexical access. Accordingly, the categorization reaction times average even longer than naming reaction times. Although there is no reason to believe that the categorization task would encourage phonological coding more than normal, silent reading, one must be cautious in interpreting the results.

Homophones and pseudohomophones have also been used in studies in which subjects read sentences while their eye movements were monitored. Daneman and colleagues (Daneman & Reingold, 1993; Daneman et al., 1995) replaced contextually appropriate words in sentences with contextually inconsistent homophones or visually similar words. For instance, the sentence, "He wore blue jeans," could have been rendered as, "He wore blew jeans," or, "He wore blow jeans." If phonology were used for word recognition, it might be expected that eye fixation times on homophone errors would be shorter than fixation times on visually similar errors. Fixation times in eye movement monitoring studies are generally reported in two ways. *First fixation duration* is the length of the initial fixation on a word, whether the initial fixation is the only fixation or the first of two or more fixations on the word. *Gaze duration* or *first-pass fixation time* is the sum of all fixation durations on the word before there is an eye movement to another word. The Daneman et al. studies found that neither first fixation durations nor gaze durations were shorter for homophone errors than for visually similar errors. They concluded there was no evidence that phonology was being used for word recognition. They did find that re-reading times were shorter for homophone errors than for visually similar errors. They attributed this effect to post-lexical phonology. Inhoff and Topolski (1994), however, conducted a similar study in which they substituted pseudohomophones (e.g. SUTE) or visually similar pseudowords (e.g. SUVE) into sentences. In contrast with Daneman and colleagues' results, Inhoff and Topolski found shorter first fixation durations and shorter gaze durations on pseudohomophones than on visually similar pseudowords. Such effects could be caused by pre-lexical phonology.

The paradigm discussed above has some advantages over other paradigms for studying word recognition. First, it is naturalistic. Subjects merely read sentences while their eyes are monitored. They need give no overt response. Second, first fixation durations and gaze durations tend to be much shorter than naming or categorization times, averaging between 200 and 350 ms. With shorter times, we can be more sure that we are dealing with early stages of word recognition. However, fixation times on contextually inappropriate words can be longer than normal fixation times, which can bring into question which processes are being measured.

A more important point should be made about the Daneman et al. (Daneman & Reingold, 1993; Daneman et al., 1995) studies, however. In their methodology, if the reader does not notice that the critical word is contextually inappropriate until after word recognition is complete, there would be no reason to expect the type of contextually inappropriate word to influence pre-lexical processing. Since the completion of word recognition requires that the critical word's homophone be inhibited (necessitating the spelling check in Van Orden's (1987) early phonology model), the fact that the contextually appropriate word is a homophone of the word in the sentence may be irrelevant until after word recognition is completed. In that case, the Daneman et al. task would tell us nothing about pre-lexical phonology. This reasoning may explain why the pseudohomophone errors in Inhoff and Topolski (1994) did confer an advantage in first fixation and gaze duration, while the Daneman et al. homophone errors did not. Since pseudohomophones do not have their own lexical entries, the lexical entries of their homophones (the contextually appropriate words) may not be inhibited during word recognition.

Because visual word recognition is such a rapid process, it is difficult to determine with many paradigms whether observed effects of phonology are due to processes during lexical access or afterward. Three paradigms attempt to deal with this issue by examining very early stages of lexical access. They are parafoveal preview (Pollatsek et al., 1992). backward masking (Perfetti & Bell, 1991; Perfetti et al., 1988), and fast priming (Rayner et al., 1995).

One way to study an early stage of lexical access is to study parafoveal preview. Many studies have shown that readers can extract information about words which are in the parafovea to the right of the word being fixated (see Rayner & Pollatsek, 1989, for a review). Even when the parafoveal word is subsequently fixated and not skipped, information processed while the word is in the parafovea aids word recognition. Some of the evidence for this view comes from boundary studies in which each sentence contains a critical word location preceded by an imaginary boundary. When a subjects' eyes cross the boundary, the critical word changes from a preview word to a target word. Rayner (1975) demonstrated a preview benefit reflected in shorter fixation durations on the target after identical previews and, to a lesser degree, after visually similar previews, in comparison with fixation durations after visually dissimilar previews.

It is believed that parafoveal processing is pre-lexical only (i.e. word recognition does not occur) when the parafoveal word is subsequently fixated. For instance, although benefits from identical and from visually similar previews have been demonstrated, Rayner, Balota, and Pollatsek (1986) were unable to demonstrate a benefit from a semantically related preview. In addition, Balota, Pollatsek, and Rayner (1985) showed that a word other than the one predicted by context is much less likely to be skipped than the predicted word. This finding suggests that if and only if parafoveal identification of a word is not possible, the parafoveal word must be fixated.

Since the nature of the parafoveal preview benefit tells us about an early stage of lexical access, it can tell us something about whether phonological processing is involved in word recognition. Pollatsek et al.

(1992) demonstrated a phonological parafoveal preview benefit using the boundary paradigm described above. First fixation durations on targets (e.g. RAINS) were shorter after a homophone preview (e.g. REINS) than after a visually similar preview (e.g. RUINS). The phonological preview benefit suggests that phonological processing does occur pre-lexically.

A big advantage of the parafoveal preview paradigm is that it seems to give us information about a pre-lexical stage of processing. In addition, since eye movement monitoring is used, no overt response is required, and the methodology is quite naturalistic (subjects are rarely aware of the display change). As mentioned above, fixation duration times are also quite short, so that they reflect less extraneous cognitive activity than longer reaction times. Given these advantages, the finding of pre-lexical phonology in this paradigm is quite striking.

The backward masking paradigm also allows one to examine early stages of word recognition. In this paradigm, the subject must identify a briefly presented target word which is followed by a briefly presented mask. In the critical conditions, the mask is either homophonically related (e.g. MAYD) to the target (e.g. MADE) or merely orthographically similar to it (e.g. MARD). Perfetti et al. (1988; Perfetti & Bell, 1991) found that homophonic masks were less disruptive to target identification than were orthographic masks. This was true even for target presentations as short as 30 ms.

Because the targets in the Perfetti experiments are presented very briefly and then masked, it is unlikely that complete word recognition could take place before the target disappears. The masks, however, can facilitate target identification by strengthening the pre-lexical information activated during the target presentation. A facilitation effect for homophonic masks greater than that for the orthographically similar masks indicates that phonology is activated pre-lexically. The existence of such an effect of phonology after only a 30 ms target presentation indicates that phonological codes are activated very early in visual word recognition.

The backward masking paradigm is not as naturalistic as the parafoveal preview paradigm, and the times to write down the identification responses are much longer. The experimental design allows complete control over the target exposure duration, however. Using very brief target exposures should allow for examination of early stages of word recognition.

Fast priming is another paradigm that allows one to investigate the early stages of lexical access. The fast priming paradigm uses eye movement monitoring. In fast priming studies (Rayner et al., 1995; Sereno & Rayner, 1992), subjects read sentences on a computer screen. As in the boundary studies mentioned above, each sentence contains a critical word location. Until the subject reaches the boundary before the critical word location, a random string of letters appears in that location. When the subject first fixates on the critical word location, a prime word is briefly presented, followed by the target word. With a prime exposure duration of only 36 ms, Rayner et al. (1995) found that subjects' eye fixations on target words (e.g. BEACH) were shorter after a homophonic prime (e.g. BEECH) than after a prime that was only visually similar (e.g. BENCH). This result indicates that phonology can be activated after a word has been visible for only 36 ms, presumably before word recognition has taken place.

Since the fast priming paradigm uses eye movement monitoring, it is more naturalistic than the backward masking paradigm. It is somewhat less naturalistic, though, than the parafoveal preview paradigm because the display change from the prime to the target is usually noticed by the subject (though the primes are rarely identified). Since fast priming is an eye movement monitoring paradigm, we can obtain first fixation durations and gaze durations which are much shorter than reaction times from other methodologies. Like the backward masking paradigm, though, fast priming studies allow us to observe the effect of very briefly presented, masked stimuli which are not identified by the subject. An effect of phonology on target fixation times after such briefly presented primes in such a naturalistic task is strong evidence for the existence of pre-lexical phonological processing.

The following experiments make use of the fast priming technique to further investigate the role of phonology in lexical access. Experiment 1 investigates whether spelling-to-sound regularity interacts with the phonological fast priming effect. Experiment 2 investigates the time course of phonological fast priming and its relationship to semantic fast priming.

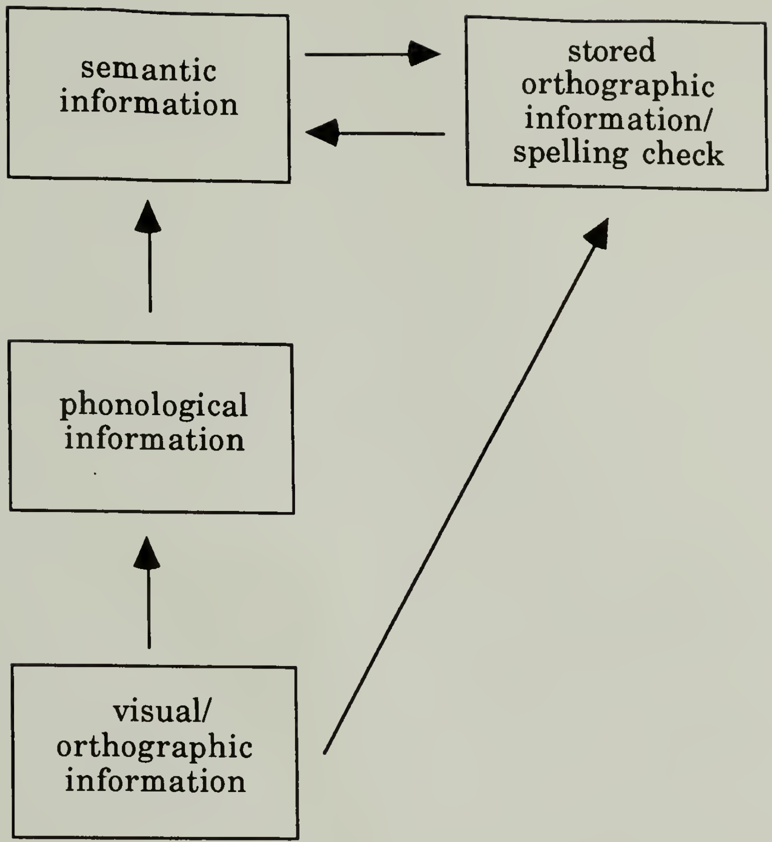

Figure 1. A simplified diagram of an early phonology model of visual word recognition along the lines of Van Orden (1987).

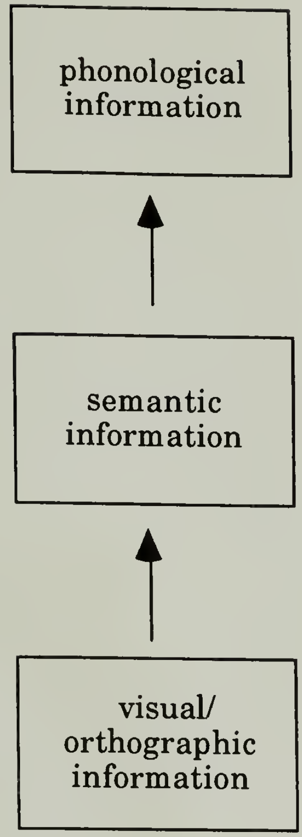

Figure 2. A simplified diagram of the usual visual word recognition process in a late phonology model.

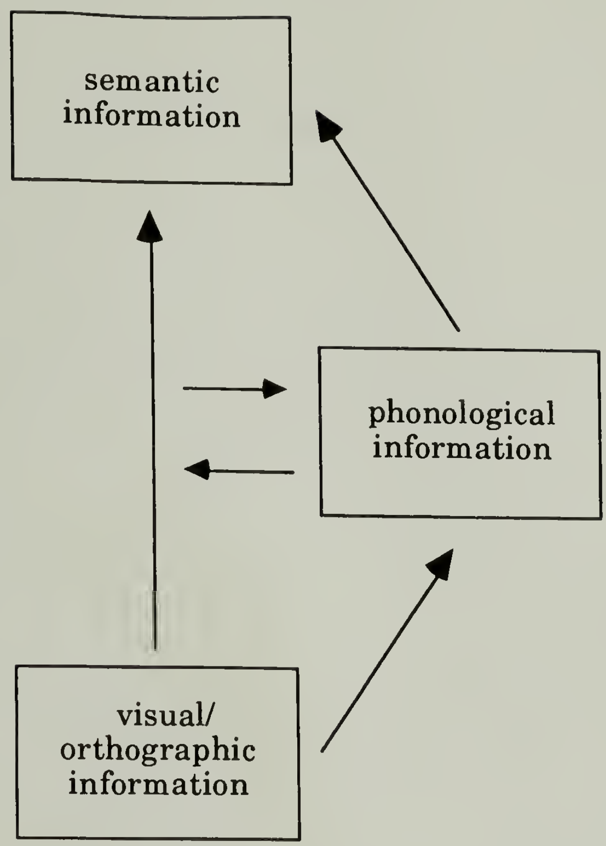

Figure 3. A simplified diagram of a dual-route model of visual word recognition. The two routes can operate independently, as in Coltheart (1978), or cooperatively, as the arrows between the two routes here illustrate, as in Carr and Pollatsek (1985).

CHAPTER 2

EXPERIMENT 1

Introduction

The phonological fast priming effect demonstrated by Rayner et al. (1995) indicates that phonology is active quite early during lexical access and is not only computed post-lexically. If the phonological fast priming effect is really due to phonological processes occurring during lexical access, then the size of the effect could be influenced by the spelling-to-sound regularity of the homophonic primes used. As discussed above, the spelling regularity of a printed word may affect how quickly the phonological code for that word may be produced pre-lexically. An effect of spelling regularity in a task, then, indicates that the task may involve pre-lexical phonological code production. If regularly spelled homophonic primes produce more priming than irregularly spelled homophonic primes, this would be further evidence that the phonological fast priming effect originates during, rather than after, lexical access.

As mentioned above, naming time studies have found low-frequency irregular words take longer to name than low-frequency regular words. Two eye movement monitoring studies have also examined the regularity effect. In an experiment by Inhoff and Topolski (1994), subjects read sentences containing regular and irregular words. No display changes were made during sentence presentation. Inhoff and Topolski found that eye fixations on regular words were significantly shorter than eye fixations on irregular words. There was no significant interaction of regularity with frequency, although there was a non-significant trend toward a larger regularity effect with low-frequency words. Sereno and Posner (1995) obtained results more consistent with naming time studies when they presented sentences under similar viewing conditions. They found a regularity effect only for low-frequency words. In another condition, however, Sereno and Posner prevented parafoveal previews of the target words by displaying a random string of letters in the target location until subjects fixated on the target location. In that condition, they found no significant effect of regularity.

Unfortunately, I was not able to examine the effects of word frequency in the present experiment. Very few homophone pairs with irregularly spelled members were available. It was not possible to include a large enough number of items in each regularity X frequency cell and also to match the visually similar primes and the homophone primes on frequency.

Method

Subjects. Fifty-six members of the University of Massachusetts community were paid or received credit to participate in the experiment. All had normal or corrected vision and were native speakers of American English.

Apparatus. Sentences were displayed on a Viewsonic 17G monitor. The monitor was controlled by an 80486 microcomputer through a VGA board. In order to make the vertical refresh rate 6.7 ms/screen (150 Hz) rather than the usual 16.7 ms/screen, the board was programmed to display 140 lines of pixels in EGA Mode 10 (normally 640 X 350 lines). The sentences were displayed in lowercase letters (except where capital letters were appropriate). The displays used Borland C++ default graphic characters, which are formed from a 7 X 8 array of dots. Characters were written to the display in a blanked mode, and the display was unblanked to begin a trial. Subjects sat 61 cm from the monitor, so that three letters equaled 1 degree of visual angle. Each sentence was displayed on a single line.

A Stanford Research Institute Dual Purkinje Eyetracker (Generation V), which was interfaced to the computer, was used to monitor subjects' eye movements. The eyetracker has a resolution of 10 min of arc (half a character). The computer sampled the eyetracker's signal once every millisecond. The subjects viewed the monitor binocularly. Eye movements were recorded from the right eye.

Materials and Design. The stimulus items for Experiment 1 are listed in Appendix A. Twenty-four homophone pairs were chosen from Hobbs (1986). In each pair, the members were matched on length. One member of each pair was used as a target, while the other was used as a homophonic (H) prime. Twelve homophone pairs (the IR pairs) were chosen to have irregularly spelled primes and regularly spelled targets. Due to the relatively small pool of words available, liberal definitions of regularity and irregularity were used. Any word with a spelling-to-sound correspondence which was an exception or a minor correspondence according to Venezky (1970) was classified as an irregular word. All other words were classified as regular words. For exception words, there are only one or two other words with similar correspondences. Minor correspondences are more common and, therefore, less irregular. Parkin (1984) found no difference in naming time between regular words and words containing minor correspondences. The fact that some of the words classified as irregular here contain minor correspondences rather than exceptions will work against finding a regularity effect.

The other twelve homophone pairs (the RR pairs) were chosen to have regular primes and targets. Each RR pair was matched on frequency with an IR pair such that the RR prime frequency approximately matched the IR prime frequency and the RR target frequency approximately matched the IR target frequency. Median frequencies per million were, for IR pairs, prime = 20.5, target = 7; for RR pairs, prime = 28, target = 11.5 (Francis & Kucera, 1982).

Twenty-four visually similar (VS) primes were also chosen. The words were matched on length to the targets and were chosen to be approximately as visually similar to the targets as the H primes were.

Each target word was embedded in each of 24 experimental sentences. The sentences were written so that the target word would not be highly predictable from context. Since Rayner et al. (1995) found priming at a nominal prime duration of 36 ms, a nominal prime duration of 35 ms was used exclusively in Experiment 1[1].

Prime type (H or VS) was counterbalanced across subject, so that each subject saw each of the 24 target items in only one of the two prime conditions. Sentences were presented in a randomized sequence.

Procedure. Subjects were told that they would read sentences on a computer monitor while their eye movements were being monitored. They were told that they would use a bite bar while reading to eliminate head movements. Subjects gave informed consent. They were told that they might notice changes in the sentences while they were reading, but that they should try to read as normally as possible. They were also told that they would occasionally be asked comprehension questions about the sentences.

Experiments 1 and 2 were run in order and in a single session for all but a few subjects. A practice block preceded the two experimental blocks to allow the subjects to become familiar with the procedure. The eyetracking system was calibrated before each block. Each calibration took approximately 5 min. A row of five boxes, extending from the beginning to the ending position of a full line of text, appeared on the screen before each sentence was displayed. A subject's eye fixation position was represented by a red dot (this was not visible during sentence displays). For a complete calibration check, subjects were instructed to look at each box. This was done before the first trial of each block and at various points during each block. Calibration at the center box and at the left-hand box were checked before each sentence.

The practice block contained 10 sentences. Experiment 1 contained 24 sentences. Experiment 2 contained 96 sentences. Before each sentence was displayed, the subject looked at the box marking the position where the sentence would begin. The sentence was then displayed. When the subject finished reading the sentence, he or she pushed a button which erased the screen. Comprehension questions were asked approximately every 5-10 sentences.

In each sentence, an invisible boundary existed after the final letter of the word preceding the target word. When each sentence was first displayed, the target word location was filled with a string of random letters. When the subject's eyes first crossed the boundary, the random letter string was changed to the prime word (see Rayner, 1975, for more on the boundary technique). Subjects were not likely to notice this change since it occurred during a saccade. The prime word was displayed for 35 ms in Experiment 1, or for 23, 29, 35, or 41 ms in Experiment 2. Prime exposure duration was measured from the onset of the subject's fixation on the prime word. The prime word was replaced by the target word after the appropriate prime duration. Subjects were likely to notice this second change. The target word remained on the screen until the subject erased the sentence.

After both experiments were completed, subjects were asked to estimate the percentage of trials in which they had noticed display changes.

They were then asked to estimate, of the trials in which they had seen a display change, how often they were sure they knew what they had seen before the change occurred. If they remembered any specific items they had seen change, they were asked to report them if they could. These questions were asked to ensure that subjects were usually not aware of the random letter strings and to ascertain how often they had been aware of the prime words. Finally, subjects were asked if they noticed a large number of homophones occurring during the experiment.

Results

Trials were excluded from the analyses in the following cases: (a) a track loss occurred; (b) the reader skipped over the target word region initially (the target word region included the space before the target word as well as the target word); (c) an eye movement crossed the boundary, triggering the display change, but the fixation following the saccade was on the word before the target; (d) the onset of the prime occurred after the onset of the fixation; (e) the first fixation on the target word lasted less than 50 ms, or the gaze duration on the target word lasted longer than 800 ms; and (f) a first-pass fixation on the target was the last recorded fixation in the sentence.

As in Sereno and Rayner (1992) and Rayner et al. (1995), a subject had to have at least 60% usable data to be included in the study. Eleven subjects did not meet this criterion and were replaced. Across the 56 subjects whose data were analyzed, 23% of their data was unusable for one of the above reasons.

In previous fast priming studies, subjects rarely reported seeing the random letter strings. In the present experiment, five subjects who reported seeing the random letter strings frequently were replaced. It was assumed that calibration with the eyetracker had not been successful for these subjects. The remaining subjects did not report seeing the random letter strings frequently.

A *first fixation duration* and a *gaze duration* were calculated for each target word. The first fixation duration is the length of the initial fixation on a word, whether the initial fixation is the only fixation or the first of two or more fixations on the word. Gaze duration is the sum of all fixation durations on the word before there is an eye movement to another word. The first fixation durations and gaze durations reported here include only time spent fixating the target. The prime exposure durations have been subtracted. The emphasis in this paper will be on gaze durations because they are thought to be more stable than first fixation durations and because they have been the primary dependent variable discussed in previous fast priming studies (Rayner et al., 1995; Sereno, 1995; Sereno & Rayner, 1992). The first fixation duration data for Experiment 1 is presented in Appendix B.

Table 1 displays the mean gaze durations for the two levels of prime regularity and the two levels of prime type. A 2 (regularity of the homophonic prime: regular or irregular) X 2 (prime type: H or VS) analysis of variance (ANOVA) was conducted on the gaze duration means. Neither the main effects nor the interaction were significant (all Fs < 1). While none of the effects were significant, it should be pointed out that the data did show a trend in the direction of the hypothesized interaction, with priming for the regular homophone primes and inhibition for the irregular homophone primes.

Table 1. Mean gaze durations in milliseconds on the target word in Experiment 1 as a function of prime type and regularity of prime.

Regularity of H Prime	Prime Type		Mean
	H	VS	
Regular H Prime	387	390	389
Irregular H Prime	394	387	391
Mean	391	389	

Discussion

Experiment 1 investigated whether the phonological fast priming effect could be influenced by the spelling regularity of the prime used. Regularly and irregularly spelled homophones as well as matched visually similar words were used as prime words in the fast priming paradigm. The prime exposure duration used was 35 ms. A regularity effect would have been further confirmation that the phonological fast priming effect is due to pre-lexical phonology.

The present experiment failed to replicate the Rayner et al. (1995) finding of a phonological fast priming effect or to find any effect of the spelling regularity of the homophonic prime used. Since the phonological fast priming effect was replicated in Experiment 2 (see below), we cannot conclude that the effect is peculiar to the Rayner et al. experiment.

One reason for the null finding in the present experiment may have to do with the prime exposure duration used. In the Rayner et al. (1995) study, phonological fast priming was found at only one of the three prime exposure durations used. It seems that using the appropriate prime exposure duration is critical for finding phonological fast priming (as it is for semantic fast priming; see Sereno and Rayner, 1992, and Sereno, 1995). Although the present study used a prime exposure duration only 1 ms different from that of Rayner et al. (1995), the equipment used in the two studies, particularly the monitors, differed. It may be that the prime exposure duration chosen for the present study is not appropriate for the equipment used. The intensity and contrast of the stimuli may have also differed in the two studies.

CHAPTER 3

EXPERIMENT 2

Introduction

Visual word recognition, like all cognitive processes, occurs over time. As discussed above, most models of visual word recognition involve progressive activation of different levels and types of information. Visual or orthographic information becomes activated first. Eventually, semantic information becomes activated. Depending on the model, phonological information becomes activated either before or after semantic information. If it is true that phonological information must be used in order to activate semantic information, then the phonological information must become activated before the semantic information. In this case, one should be able to observe effects of activated phonological information earlier during word recognition than one can observe effects of activated semantic information.

Because the fast priming technique allows one to observe what processes are active during early stages of lexical access, it is an excellent tool to use to determine the time course of phonological and semantic activation during word recognition. Investigations of phonological processes with the fast priming technique have been discussed above. Semantic processes have also been examined with the fast priming technique. Sereno and Rayner (1992; Sereno, 1995) have shown that fixations on targets after semantically related primes are shorter than fixations on targets after semantically unrelated primes. As with the phonological fast priming studies, prime exposure durations in the semantic fast priming study were very brief, indicating that semantic information becomes active quite early during lexical access.

The question addressed in Experiment 2, then, is whether semantic information becomes active after, before, or concurrent with the activation of phonological information. By measuring both phonological and semantic fast priming in the same experiment, and by varying the prime exposure durations used for both, it should be possible to determine the time course of activation of phonological and semantic information in visual word recognition. If phonological codes are truly activated before semantic codes are activated, then phonological fast priming should first appear at a shorter prime exposure duration than that at which semantic fast priming first appears.

In previous experiments, phonological and semantic fast priming have been found at varying prime exposure durations. Sereno and Rayner (1992) found semantic fast priming at a prime duration of 30 ms, but not at prime durations of 21, 39, 45, or 60 ms. Sereno (1995) found semantic fast priming at a prime duration of 35 ms, but not at prime durations of 25 and 30 ms. In their study of phonological fast priming, Rayner et al. (1995) found priming at a prime duration of 36 ms, but not at 24 or 30 ms. Of course, these three experiments all involved different sets of subjects and different display monitors. In addition, the phonological fast priming study used a different set of materials than the semantic fast priming studies.

In Experiment 2, we presented a single set of subjects with a single set of targets and sentences. Primes were either homophonic (H), visually similar (VS), semantically related (R), or semantically unrelated (U) to the target word. Prime duration was varied between 23, 29, 35, and 41 ms.

<u>Method</u>

<u>Subjects</u>. Forty-eight members of the University of Massachusetts community were paid or received credit to participate in the experiment. All

had normal or corrected vision and were native speakers of American English. Each of these subjects also participated in Experiment 1.

Apparatus. The apparatus was identical to that used in Experiment 1.

Materials and Design. The stimulus items for Experiment 2 are listed in Appendix C. Ninety-six members of homophone pairs were chosen from Hobbs (1986) to serve as targets in Experiment 2. H, VS, R, and U primes were chosen for each target. Twenty-one of the H primes from Experiment 1 served as targets in Experiment 2 (with their Experiment 1 targets serving here as H primes). In addition, each member of 29 homophone pairs served as a target in one Experiment 2 item and as an H prime in another item (with its homophone serving in the corresponding role). All primes and targets were matched on length.

As in Experiment 1, the VS primes were chosen to be approximately as visually similar to the targets as the H primes were. The R primes were chosen to be semantically related to the target word, while the U primes were chosen to be semantically unrelated to the target word.

Each target word was embedded in each of 96 experimental sentences. The sentences were written so that the target word would not be highly predictable from context. The prime durations used were 23, 29, 35, and 41 ms.

The combination of four prime types (H, VS, R, and U) with four prime durations (23, 29, 35, and 41 ms) created 16 conditions. The conditions were counterbalanced across subject, so that each subject saw each of the 96 target items in only one of the 16 conditions. Sentences were presented in a randomized sequence.

Procedure. See Experiment 1.

Results

Trials were excluded from the analyses by the same criteria as in Experiment 1.

As in Experiment 1, a subject had to have at least 60% usable data to be included in the study. Seven subjects did not meet this criterion and were replaced. In addition, one subject had no data remaining in one cell after exclusions were made. This subject was also replaced. Across the 48 subjects whose data were analyzed, 26% of their data was unusable for one of the above reasons.

Also, four subjects who reported seeing the random letter strings frequently were replaced. As in Experiment 1, it was assumed that calibration with the eyetracker had not been successful for these subjects. The remaining subjects did not report seeing the random letter strings frequently.

All but six of the subjects whose data were analyzed in Experiment 2 also had data analyzed in Experiment 1. Fourteen subjects whose data were analyzed in Experiment 1 did not have data analyzed in Experiment 2 (eight of these subjects never completed Experiment 2).

As in Experiment 1, a first fixation duration and a gaze duration were calculated for each target word. Also, as in Experiment 1, the first fixation durations and gaze durations include only time spent fixating the target. The prime exposure durations have been subtracted. First fixation duration data for Experiment 2 data are listed in Appendix D.

Table 2 displays the mean gaze durations for the four levels of prime duration and the four levels of prime type. Separate ANOVAs were conducted to test for effects of phonological and semantic priming. To test for effects of phonological priming, a 4 (prime duration: 23, 29, 35, or 41 ms) X 2 (prime type: H or VS) ANOVA was conducted on the gaze duration means. The main effect of prime duration was significant, $F(3, 141) = 3.93$, $p < .05$. Effects of prime duration will be analyzed in more detail below for all four prime types together. The main effect of prime type was also significant, $F(1, 47) = 4.93$, $p < .05$. Averaged over the four prime durations, mean gaze durations in the homophonic prime condition were 14 ms shorter than in the visually similar prime condition. The interaction of prime duration and prime type was not significant, $F(3, 141) = 1.70$, $p = .17$.

Table 2. Mean gaze durations in milliseconds on the target word in Experiment 2 as a function of prime duration and prime type.

Prime Duration (in ms)	Prime Type				Prime Type			
	H	VS	Mean	VS-H	R	U	Mean	U-R
23	364	370	367	6	401	385	393	-16
29	361	388	374	27	408	410	409	2
35	391	392	391	1	411	383	397	-28
41	363	387	375	24	401	403	402	2
Mean	370	384		14	405	395		-10

Although the interaction was not significant, examination of the means in Table 2 indicated that more priming occurred at some prime durations than others. Contrasts indicated a significant 27 ms phonological priming effect at the 29 ms prime duration, $F(1, 47) = 6.25$, $p < .05$, and a significant 24 ms phonological priming effect at the 41 ms prime duration, $F(1, 47) = 4.44$, $p < .05$. There were no significant effects of priming at the 23 or 35 ms prime exposure durations, Fs < 1.

A 4 (prime duration: 23, 29, 35, or 41 ms) X 2 (prime type: R or U) ANOVA was conducted on the gaze duration means to test for effects of semantic priming. The main effect of prime type was significant, $F(1, 47) = 4.89$, $p < .05$. Averaged over the four prime durations, mean gaze durations in the semantically related prime condition were actually 10 ms longer than in the semantically unrelated prime condition. The main effect of prime duration was not significant, $F(3, 141) = 1.91$, $p = .13$, and the interaction of prime duration and prime type was not significant, $F(3, 141) = 2.13$, $p = .10$.

Again, although the interaction was not significant, the Table 2 means indicated that two of the prime exposure durations were responsible for the significant main effect of inhibition. Contrasts showed a significant 28 ms inhibition effect at the 35 ms prime duration, $F(1, 47) = 7.42$, $p < .01$. There was also a marginally significant 16 ms inhibition effect at the 23 ms prime duration, $F(1, 47) = 2.87$, $p < .10$. The effects at the 29 and 41 ms prime durations were not significant, Fs < 1.

A further ANOVA was conducted to test for effects of visual similarity of the prime to the target and to explore further the effects of prime duration. The H and VS prime conditions were both visually similar to the target, while the R and U prime conditions were not. For the purposes of the present analysis, then, H and VS conditions were combined and compared to the R and U conditions combined. Table 3 displays the resulting mean gaze durations. In this analysis, it is possible to examine the effects of prime duration averaged across all four prime types. A 4 (prime duration: 23, 29, 35, or 41 ms) X 2 (prime visual similarity: H/VS or R/U) ANOVA was conducted on the mean gaze durations. The main effect of prime visual similarity was significant, $F(1, 47) = 35.3$, $p < .001$. The H/VS gaze durations were on average 23 ms shorter than the R/U gaze durations. The main effect of prime duration was also significant, $F(3, 141) = 3.28$, $p < .05$. In addition, the interaction of prime visual similarity and prime duration was significant, $F(3, 141) = 2.76$, $p < .05$.

Table 3. Mean gaze durations in milliseconds on the target word in Experiment 2 as a function of prime visual similarity and prime duration.

Prime Duration (in ms)	Prime Visual Similarity H/VS	R/U	Mean
23	367	393	380
29	374	409	391
35	391	397	394
41	375	402	388
Mean	377	400	

The main effect of prime duration was primarily due to the speed of the gaze durations at the 23 ms prime duration relative to the other prime durations. The 11 ms difference between the mean gaze durations at the 23 ms prime duration and at the 29 ms prime duration was significant, $F(1, 47) = 6.21$, $p < .05$. The 14 ms difference between the mean gaze durations at the 23 ms prime duration and at the 35 ms prime duration was also significant, $F(1, 47) = 9.65$, $p < .01$. Finally, the 8 ms difference between the mean gaze durations at 23 ms and at 41 ms was marginally significant, $F(1, 47) = 2.87$, $p < .10$.

The significant interaction between prime visual similarity and prime duration is due to the fact that the effect of prime visual similarity was significant at all prime durations except the 35 ms prime duration. The 26 ms effect of prime visual similarity at the 23 ms prime duration was significant, $F(1, 47) = 15.35$, $p < .001$. The 35 ms effect of prime visual similarity at the 29 ms prime duration was significant, $F(1, 47) = 17.38$, $p <$

.001. Lastly, the 27 ms effect of prime visual similarity at the 41 ms prime duration was significant, $F(1, 47) = 10.87$, $p < .01$.

Discussion

Experiment 2 attempted to investigate the time course of activation of phonological and semantic information during visual word recognition. Within the fast priming paradigm, homophonic and visually similar primes were used to investigate phonological fast priming, while semantically related and semantically unrelated primes were used to investigate semantic fast priming. Four different prime exposure durations were used: 23, 29, 35, and 41 ms.

In contrast with Experiment 1, phonological fast priming was obtained in Experiment 2, replicating the effect found by Rayner et al. (1995). Though contrasts indicated significant phonological fast priming effects only at the prime exposure durations 29 and 41 ms, the interaction of prime type with prime duration was not significant.

The case of semantic fast priming is more complicated. While there was a significant effect of prime type, the effect was in the opposite direction than that predicted by priming and that has been found in previous semantic fast priming studies (Sereno & Rayner, 1992; Sereno, 1995). Averaged across all four prime durations, a 10 ms inhibition effect was found; gaze durations on targets were longer on average after semantically related primes than after semantically unrelated primes. While the inhibition effect does demonstrate the activation of semantic information in the same way that a priming effect would, it is not clear why inhibition rather than priming was obtained in this study. This topic will be discussed further in Chapter 4. While contrasts indicated that the inhibition effect was significant at the 35 ms prime duration, marginally significant at the 23 ms prime duration, and not significant at the remaining prime durations, the interaction of prime duration and prime type was again not significant.

Since neither phonological fast priming nor semantic fast priming/inhibition interacted with prime exposure duration, this study does not allow us to determine for certain the time course of activation of phonological and semantic information during visual word recognition. However, contrasts indicated a marginally significant semantic inhibition effect at the earliest prime exposure duration, while no phonological effect was apparent at that duration. This would seem to indicate that semantic information is activated before phonological information during word recognition.

We cannot be certain of this conclusion, however, for several reasons. First of all, as was mentioned above, the interactions of prime type and prime duration were not significant in the ANOVAs performed to examine the phonological and semantic priming effects. Since the interactions were not significant, we can only speculate about which prime exposure durations are truly responsible for the effects. Second, the earliest prime exposure duration used in this study, 23 ms, was chosen because it was thought that no effects would be found at that duration. Since a marginally significant semantic inhibition effect was obtained in the contrast for that duration, it is possible that effects could be obtained at earlier durations. Before we can say that semantic information is activated before phonological information, we must examine shorter prime exposure durations. Lastly, a very strange pattern was found in the phonological and semantic priming/inhibition effect contrasts. In previous fast priming studies, only three prime durations were examined, and priming was never obtained at more than one prime duration. Here, four prime durations were examined. For both the phonological and semantic effects, priming/inhibition seemed to appear, disappear, and then reappear as the prime exposure duration increased. Instead of finding a window within which each effect can be obtained, we have a much more complicated pattern of results. Until this pattern can be explained, we cannot be sure what the time course of phonological and semantic activation truly is.

CHAPTER 4

GENERAL DISCUSSION

The most important positive finding of this study is the replication in Experiment 2 of the Rayner et al. (1995) phonological fast priming effect. As in the Rayner et al. study, gaze durations on targets were shorter after homophonic primes than after visually similar primes. This effect demonstrates again that phonological processing is active very early during word recognition.

Experiment 2 also resulted in a partial replication of the semantic fast priming effect found in Sereno and Rayner (1992) and Sereno (1995). In Experiment 2, gaze durations on the target were significantly different after semantically related primes than after semantically unrelated primes. However, instead of priming, inhibition was obtained in Experiment 2.

The reason for the inhibition result rather than a priming result is unclear. Examination of the stimuli used in Experiment 2 in comparison with the Sereno and Rayner (1992) stimuli revealed several differences between the sets of stimuli. It is possible that these differences could have caused the disparity between the results obtained in the two experiments. The differences were, as follows: (1) The Sereno and Rayner (1992) stimuli contained a high proportion of associatively related pairs as opposed to semantically related, unassociated pairs. The stimuli in Experiment 2 may have contained a higher proportion of semantically related, unassociated pairs than the Sereno and Rayner stimuli did. Some researchers have argued that purely semantic priming is qualitatively different from associative priming (see, e.g. Shelton & Martin, 1992). (2) The Sereno and Rayner (1992) related primes seem to have meanings more similar to those of their targets than the Experiment 2 related primes do. It is possible that strongly related primes may lead to priming in the present paradigm while more weakly related primes may lead to inhibition. (3) Target words in the presented stimuli tended to appear later in the sentence than did target words in the Sereno and Rayner (1992) stimuli. It is possible that priming might be more likely with early targets due to a smaller memory load.

Post-hoc analyses were performed to determine if any of these differences might have been responsible for the present inhibition result. For each hypothesized relevant dimension, the present stimuli were divided into those more like the Sereno and Rayner (1992) stimuli and those less like them. The results of these analyses provided no evidence that the inhibition obtained in Experiment 2 could have been attributed to any of these differences.

The present experiments reveal how much we have left to learn about the fast priming task. Experiment 1 demonstrates the risk in conducting a fast priming experiment using only one prime exposure duration. With only one prime duration, a null finding is impossible to interpret. Experiment 2 shows that the fast "priming" task can result in inhibition instead of priming. We do not yet understand what conditions are favorable for priming or for inhibition. In addition, we cannot explain yet why effects seem to appear at some prime exposure durations but not others. Much further work is needed until we can fully understand the characteristics of the fast priming task.

Unfortunately, the present experiments do not answer the questions they were intended to answer. We do not know whether regularity might interact with the phonological fast priming effect at a different prime exposure duration. If it did, this would further confirm that phonological fast priming is due to pre-lexical phonology. We also cannot say for certain what the time course of activation of phonological and semantic information are in early lexical processing. It is hoped that further fast priming experiments can resolve these questions.

APPENDIX A

EXPERIMENT 1 STIMULI

Irregular-regular (IR) homophone pairs	H prime	VS prime
The professor said that other *suns* might have habitable planets.	sons	sins
John decided to *pare* the guest list down to twenty people.	pear	perk
With the magnifying glass I could see each *pore* in my hand.	pour	port
The police were told not to *shoot* unless lives were in danger.	chute	white
Some people tend to *hoard* supplies before a big storm.	horde	heard
They needed a mallet to push the *stake* into the ground.	steak	stark
There was a big rip in the *sole* of one of her shoes.	soul	soil
Because my head was *bare* I got very cold on my way home.	bear	bore
There was no time to *warn* the city about the tidal wave.	worn	wary
Susan hit the *brake* when she saw the deer in the road.	break	brave
My friends were *right* when they said the party would be fun.	write	trite
The recipe said to *grate* the cheese into the mixture.	great	grant
Regular-regular (RR) homophone pairs		
Liz said that the *seas* had been treacherous during her voyage.	sees	sews
The angry lion would surely *maul* anyone who entered the cage.	mall	mail
Mike liked to go to the *flea* market every Sunday afternoon.	flee	flew
I will be the first one at the *beach* when summer gets here.	beech	bench
The floors in the apartment *creak* because they're so old.	creek	croak
The first club meeting was a big *waste* of everyone's time.	waist	water
The musicians had to *haul* away the trash they had dumped.	hall	hail
He assumed it was the *male* cat because it was named Sebastian.	mail	maul
The mythological animal's *tail* was more than ten feet long.	tale	talk
The zoologist had to *stalk* the animal for two hours to catch it.	stock	stink
Deborah asked for another *piece* of the delicious lasagna.	peace	price
The children were extremely *bored* during the long car ride.	board	boxer

APPENDIX B

EXPERIMENT 1 FIRST FIXATION DURATIONS IN MILLISECONDS

Regularity of Prime	Prime Type		Mean
	H	VS	
Regular Prime	342	350	346
Irregular Prime	336	332	334
Mean	339	341	

APPENDIX C

EXPERIMENT 2 STIMULI

	H prime	VS prime	R prime	U prime
Jessica had two *sons* and a daughter from her first marriage.	suns	sins	dads	hail
I bought the best *pear* I've eaten in years at that store.	pare	pray	plum	desk
Catherine asked Dave to *pour* her a glass of orange juice.	pore	port	rain	unit
We were thrilled to see the *bear* that we saw at Yellowstone.	bare	bran	wolf	town
Paul said he hadn't *worn* a tuxedo since his high school prom.	warn	worm	used	fall
The landlord showed us the *chute* that went to the incinerator.	shoot	shirt	slide	flame
Luckily, I didn't *break* the glass when I accidentally dropped it.	brake	bread	crack	trite
Every day a small *horde* of children descended on the playground.	hoard	hover	crowd	price
Janet had vowed to *write* her first novel before she turned 30.	right	strip	paper	train
Their reputation was built on the fine *steak* that they served.	stake	stack	meats	raise
Skiing and ice skating are *great* ways to enjoy the winter.	grate	grant	awful	spike
The teacher becomes furious when he *sees* a student fall asleep.	seas	sews	eyes	herb
Most people go to the *mall* when they need to do shopping.	maul	malt	shop	free
The people were advised to *flee* before the invaders arrived.	flea	flew	runs	soup
They found two tons of *mail* that had been hidden on the lot.	male	malt	post	plow
Lisa knows another *tale* that's even scarier than that one is.	tail	tame	myth	flow
Their new property has predominantly *beech* and oak trees.	beach	bench	trees	stale
They wished they had bought *stock* in Microsoft ten years ago.	stalk	stink	bonds	pleat
Near his house there had been a small *creek* and some woods.	creak	creep	river	smart

The people wanted *peace* even though the leaders wanted war.	piece	place	quiet	chair
She bought a wooden *board* and some bricks to make a shelf.	bored	broad	plank	crash
The restaurant served several *ales* that were brewed locally.	ails	awls	beer	trip
If the leader *dies* in office, there will be a power struggle.	dyes	does	live	swap
They say that the actress *dyes* her hair to look younger.	dies	does	inks	roar
We lost our *oars* when the canoe was overturned in the rapids.	ores	orbs	boat	hire
A scientist was hired to find *ores* for the company to mine.	oars	ours	iron	turn
Tom saw many *firs* and pines when he toured the Northwest.	furs	fire	tree	sane
Jane gave away her *furs* after joining an animal rights group.	firs	fuss	mink	moat
The farmer tripped over the *pail* on his way out of the barn.	pale	palm	milk	tore
After his sickness, Doug was very *pale* for several weeks.	pail	pelt	dark	disk
Clair knew how to *sail* but knew nothing about surfing.	sale	salt	boat	care
Doug went to the big *sale* at the department store Saturday.	sail	self	shop	drip
Yesterday, the celebrity *beat* someone up in a bar fight.	beet	best	hurt	wine
Meg was happy when she *blew* out all the candles on the cake.	blue	bled	wind	ripe
The suspect was seen driving the *blue* sedan north on I-91.	blew	bled	pink	work
The children saw the *boar* when they went to the zoo today.	bore	born	pigs	late
Television shows about nature *bore* him most of the time.	boar	boor	dull	nail
The only item of furniture in the entire *cell* was a bunk bed.	sell	fell	jail	soap
It was difficult to *sell* the strangely constructed house.	cell	tell	buys	tune
Matt would not give one *cent* to that political candidate.	sent	vent	cash	nice
If he hadn't seen the ad, he would never have *sent* his resume.	cent	went	mail	tuna
Ann was angry when she saw a man giving the *deer* potato chips.	dear	deed	fawn	spit

Diane went to the *fair* so she could go on the ferris wheel.	fare	farm	just	pine
Because she didn't have the *fare* for the subway, she walked.	fair	fern	cost	nook
When details of his *feat* became known, George was a hero.	feet	felt	deed	trim
After two hours outside in the cold, my *feet* were freezing.	feat	felt	toes	loss
There was a quite *foul* smell emanating from the basement.	fowl	foil	odor	wire
The cookbook contained recipes for fish, *fowl*, and vegetables.	foul	foil	bird	bulk
Since she was late for school, her *gait* was quite swift.	gate	gnat	walk	file
He arrived to find the *gate* open and all his horses gone.	gait	gets	door	pool
Marie hoped that her leg would *heal* before the big game.	heel	hell	cure	mice
She tripped when the *heel* of one of her shoes broke off.	heal	hell	shoe	task
No one could *hear* the speaker because he spoke so quietly.	here	hers	sees	skip
They did not fix the *leak* until the damage got quite bad.	leek	lead	drip	snob
On her day off she *made* pottery at the arts and crafts center.	maid	male	done	bite
The distinctive *mane* a lion has makes it easily recognizable.	main	menu	lion	fork
Steve was disappointed at the amount of *meat* in his dish.	meet	melt	beef	fast
Helen had some *pain* after the operation, but the pills helped.	pane	pans	hurt	rule
When we got to the *peak* of the mountain, we loved the view.	peek	peck	tops	gill
We took a quick *peek* in the window to see if Greg was home.	peak	peck	sees	rope
They said that the *peal* of the bell was audible for miles.	peel	peak	ring	wise
He had to *peel* twenty potatoes to prepare for the holiday meal.	peal	peek	rind	sigh
The astronomer invited people to *peer* through the telescope.	pier	peel	look	load
During the hurricane, the *pier* received quite a beating.	peer	pies	dock	hand
The newspaper reported the *poll* about drug and alcohol use.	pole	pool	vote	kill

We were mortified when the *ball* went through the window.	bawl	bail	roll	mine
The children started to *bawl* whenever their parents went out.	ball	bail	sobs	hill
The President asked us to *pray* for the disaster victims.	prey	play	amen	tour
The tigers are cut off from their natural *prey* by a cliff.	pray	trey	hunt	sand
When the *rain* began to fall, she was already sound asleep.	rein	ruin	snow	joke
He dropped the *rein* and then had no control over the horse.	rain	ruin	mare	tile
She did not believe the plant was *real* until she touched it.	reel	read	true	loaf
We left in the middle of the second *reel* of the boring film.	real	reek	film	quit
Jennifer and Chris were glad to be on the *road* to California.	rode	rods	cars	wilt
To get his exercise he *rode* his bicycle to and from work daily.	road	reds	bike	full
The toy cars *roll* better on the wood floor than on the carpet.	role	roil	ball	frog
It was embarrassing when the *seam* ripped during the party.	seem	sear	sews	nose
Sunday Tracy went to watch the hanggliders *soar* into the sky.	sore	sort	bird	milk
We were all *sore* after hiking ten miles the previous day.	soar	sour	pain	path
Usually the *team* had pizza on Wednesday nights at Sally's.	teem	term	game	past
Our belongings were drenched by water when the *tide* came in.	tied	tile	seas	slim
After they *tied* the luggage to the roof, they drove away.	tide	tier	knot	roof
Since no *vein* was cut, the wound was not a major emergency.	vain	veil	bled	like
Bill felt very *weak* after watching the bodybuilders on TV.	week	wear	puny	rock
Michelle went to the Caribbean one *week* during January.	weak	weed	days	slit
He bought her a red *rose* and took her to dinner last night.	rows	rots	pink	cave
The fugitive walked stealthily between the *rows* of corn.	rose	rots	line	call
Mark must have *grown* a foot since we last saw him in May.	groan	groin	adult	cider

She preferred her bedroom to be *plain* and uncluttered.	plane	plant	fancy	chart
On the *plane* to Chicago, he met a very interesting woman.	plain	place	pilot	brown
Rita didn't have enough *sense* to come in out of the rain.	cents	rents	think	thorn
One must not *knead* the dough too much when making a pie crust.	kneed	kneel	dough	prose
When Bob bent down to get the knife, Dan *kneed* him in the face.	knead	kneel	kicks	stove
She skipped every other *stair* as she ran to the tower's top.	stare	stars	steps	fresh
He could not believe that someone would *steal* his ancient car.	steel	steak	thief	power
She worked for the *steel* mill before it shut down last year.	steal	steer	metal	court

APPENDIX D

EXPERIMENT 2 FIRST FIXATION DURATIONS IN MILLISECONDS

Prime Duration (in ms)	Prime Type		Mean
	H	VS	
23	330	325	327
29	330	346	338
35	351	347	349
41	336	329	333
Mean	337	337	

Prime Duration (in ms)	Prime Type		Mean
	R	U	
23	365	354	359
29	365	366	366
35	372	344	358
41	362	368	365
Mean	366	358	

NOTES

[1]For all the fast priming experiments described in this paper, the prime exposure durations are only nominal for the following reason: The prime exposure is taken to begin when the subject's fixation on the prime word begins. After the nominal prime duration (35 ms in Experiment 1) has passed, the computer gives the command to replace the prime word with the target word. Because the screen refreshes at a set rate, the target word will actually replace the prime word at some random time after the command to execute the change. In the present experiments, the screen refresh rate was 6.7 ms/screen. Therefore, the target word actually replaced the prime word at some random time 0 - 6.7 ms after the command to make the change.

It should also be noted that the intended nominal prime duration of Experiment 1 was 36 ms in order to match the nominal prime duration at which Rayner et al. (1995) found priming effects. Due to a programming error, all of the nominal prime durations in Experiments 1 and 2 were 1 ms shorter than intended.

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